MICRO PUMP USING FERROFLUID OR MAGNETO-RHEOLOGICAL FLUID

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates to a micro pump using ferrofluid or magneto-rheological fluid, and more particularly, to a micro pump that improves flow and pump efficiency.

Description of the Related Art

The micro fluid control device fabricated by microelectromechanical system (MEMS) technology is characterized by having a small size, precise flow control, and fast reaction time. As the micro fluid control device can be integrated with the conventional micro sensor on the same system for a feedback control, a large batch of the micro fluid control devices may be manufactured. Therefore, the micro fluid device has become one device that is worth of researches and widely implemented in the industry.

For a micro pump component in the micro fluid control device, its related technology has been developed to a matured stage, so the micro pump component has been applied to different fields, such as chemical analysis, biomedical system, micro cooling system, and so on. Typically, a membrane type micro pump 80 shown in FIG. 11 is adopted. The micro pump 80 has two membrane type valves 81 that serve as an entrance 82 and an exit 83 respectively for an external working fluid to enter or exit the micro pump 80, while flow direction control for the working fluid is also provided by

the valves 81. However, after a long-term use, the valves and moving parts are gradually worn out to lose their reliability, even causing fatigue at valve connector ends in some cases. Such valve design may eventually lead to loss of the fluid pressure, which in turn reduces flow to be driven by the pump or causes contamination due to back flow of the working fluid.

Then, a valve-less micro pump 85 that uses a piezoelectric material as a driving source is proposed as shown in FIGs. 12A and 12B. A piezoelectric piece 86 made of piezoelectric material serves as a driving source for the working fluid to cause deformation of the piezoelectric piece 86 via a voltage control. As a result, the external working fluid is driven to flow into the micro pump 85 as shown in FIG. 12A or flow out of the micro pump 85 as shown in FIG. 12B. Although the design is free from problems associated with the above mentioned valves and moving parts, deformation level of the piezoelectric piece 86 is limited by its material characteristics , so the output flow is consequently limited. Thus, it is difficult to satisfy the commercial need with the valve-less micro pump 85. Also, back flow may occur to reduce efficiency in driving the working fluid and cause contamination of the working fluid when the micro pump of the above design is operated.

The later design utilizes a ferromagnetic-fluid to drive the working fluid in the micro pump so as to achieve a higher driving efficiency and flow. Referring to FIG. 13, the design involves a round closed tubing 90, which is filled with the working fluid 91 and a section of ferro-magnetic fluid 92. An entrance 93 and an exit 94 are formed respectively on the tubing 90 to open to outside, and a fixed magnet 95 is disposed in between the entrance 93 and the exit 94. A moving magnet 96 is formed on the inner side of the tubing 90 to move along the tubing 90, so that ferro-magnetic fluid 92 is

driven by the moving magnet 96 to move within the tubing 90. A valve door is formed at either the entrance 93 or exit 94 of the tubing 90 via the fixed magnet 95. The valve door is operated as illustrated to drive the working fluid 91 entering from the entrance 93 to discharge out of the exit 94, so as to complete a pump cycle. However, despite of efficiency in terms of driving the working fluid, serious contamination problem caused by mixing the working fluid 91 and the ferro-magnetic fluid 92 is not taken into account in designing this micro pump. When the micro pump is applicable to fields, such as chemical analysis and biomedical system, it is often required that the working fluid to be driven by the pump has a high purity. While the micro pump of such design is operated as such, the working fluid 91 to be discharged clearly does not fulfill such requirement, and the contamination problem gets worse as the operation time gets longer, making such design unpractical in terms of fulfilling the industrial demand.

Therefore, it is an objective for this field of art to develop a micro pump that improves its driving flow and controls precision of flow to prevent the back flow of the working fluid, so as to prevent contamination of the working fluid.

SUMMARY OF THE INVENTION

The primary objective of the present invention is to provide a micro pump using ferrofluid or megneto-rheological fluid, which micro pump improves flow and pump efficiency.

Another objective of the present invention is to provide a micro pump using ferrofluid or megneto-rheological fluid, which micro pump precisely controls flow.

One other objective of the present invention is to provide a micro pump using ferrofluid or megneto-rheological fluid, which micro pump prevents back flow of a working fluid.

A further objective of the present invention is to provide a micro pump using ferrofluid or megneto-rheological fluid, which micro pump has a high reaction ferquency.

And yet another objective of the present invention is to provide a micro pump using ferrofluid or megneto-rheological fluid without contaminating the working fluid.

And yet one other objective of the present invention is to provide a micro pump using ferrofluid or megneto-rheological fluid without wearing out moving parts of the pump.

And yet further objective of the present invention is to provide a micro pump using ferrofluid or megneto-rheological fluid, which micro pump reduces loss of fluid pressure.

And still another objective of the present invention is to provide a micro pump using ferrofluid or megneto-rheological fluid without limiting its appearance.

In accordance with the above and other objectives, the present invention proposes the micro pump that uses ferrofluid or megneto-rheological fluid to drive the working fluid. The micro pump has at least a micro pump component, each component comprises a body having an accommodating space formed therein and an opening that communicates with the accommodating space. A membrane is formed in the accommodating space to separate a first space and a second space in such a way that the second space communicates with the opening. The second space is filled with a working fluid. The micro pump component also comprises a ferro-fluid/magneto-

rheological fluid that fills the first space and a magnetic field generating component that applies magnetic field to the accommodating space. As a result, the membrane is deformed constantly via the ferro-fluid/magneto-rheological fluid to drive the working fluid flowing through the opening.

The present invention proposes another micro pump component that comprises a body having an accommodating space formed therein and at least an opening that communicates with the accommodating space. The accommodating space is filled with the working fluid. The micro pump component further comprises at least two ferro-fluid/magneto-rheological fluid components located respectively on two corresponding sides of the accommodating space, and magnetic filed generating component for driving the at least two ferro-fluid/magneto-rheological fluid components. Consequently, a constant shifting is generated for the ferro-fluid/magneto-rheological fluid components in order to drive the working fluid flowing through the opening.

Each of the ferro-fluid/magneto-rheological fluid components is a ferro-fluid/magneto-rheological fluid immiscible to the working fluid or a ferro-fluid/magneto-rheological fluid molded by encapsulating in the membrane. The ferro-fluid/magneto-rheological fluid includes iron or ferroxide particles, wherein the particles are attracted to each other when they are magnetized by an external magnetic field to align in the same direction, so that the ferro-fluid/magneto-rheological fluid is transformed within a few seconds into a magnetic solid. As the magnetic field is removed, the magnetic particles return to particle bombardments to evenly distribute in the ferro-fluid/magneto-rheological fluid. As a result, the solidified ferro-fluid/magneto-rheological fluid is quickly changed to a liquid form.

As the ferro-fluid/magneto-rheological fluid is magnetized by the magnetic field to transform into the magnetic solid, the magnetic solid is attracted by the magnetic field to produce deformation and position shifting, such that the working fluid can be driven by the deformation and position shifting to flow in/out of the body of the micro pump to achieve pump function.

There are two openings formed on the body serving respectively as entrance and exit for the working fluid to flow in/out of the accommodating space, and the two openings are formed as a diffuser and a nozzle. Meanwhile, an opening control device is further formed on the opening for opening the exit and closing the entrance when the working fluid is required to flow out via the exit. Similarly, the opening control device communicates the entrance and closes the exit when the working fluid is required to flow in via the entrance. The opening control device further comprises another ferro-fluid/magneto-rheological fluid driven by the magnetic field to shift in such a way as to precisely control closing of the entrance and exit. Therefore, back flow of the working fluid is prevented, while efficiency in driving the working fluid is also improved.

According to the micro pump of the present invention, characteristics of the ferro-fluid/magneto-rheological fluid where the ferro-fluid/magneto-rheological fluid is attracted by the magnetic field after the fluid is magnetized and solidified may be adopted. With the ferro-fluid/magneto-rheological fluid serving as a source for driving the working fluid, input/output of the working fluid may be controlled via deformation and position shifting of the ferro-fluid/magneto-rheological fluid, and both pump efficiency and output flow of the micro pump are significantly improved. Meanwhile, the flow may be precisely controlled via opening control device made of ferro-fluid/magneto-rheological fluid to prevent occurrence of the back flow.

To provide a further understanding of the invention, the following detailed description illustrates embodiments and examples of the invention, it is to be understood that this detailed description is being provided only for illustration of the invention and not as limiting the scope of this invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings included herein provide a further understanding of the invention. A brief introduction of the drawings is as follows:

FIG. 1 is a cross-sectional view of a micro pump according to the first embodiment of the present invention;

FIG. 2A is a schematic diagram illustrating the magneto-rheological fluid component without influence of the magnetic field;

FIG. 2B is a schematic diagram illustrating a solidified magneto-rheological fluid after being magnetized by a magnetic field;

FIG. 3A is a cross-sectional view illustrating operation of the first embodiment shown in FIG. 1 in its pump mode;

FIG. 3B is a cross-sectional view illustrating operation of the first embodiment shown in FIG. 1 in its supply mode;

FIG. 4 is a cross-sectional view illustrating a pump module assembled by the first embodiment shown in FIG. 1;

FIG. 5A is an elevation view illustrating the micro pump without a top lid disposed thereon according to the second embodiment of the present invention;

FIG. 5B is an elevation view illustrating the top lid of the micro pump according to the second embodiment of the present invention;

FIG. 6A is a schematic diagram illustrating shifting of two movable magnets shown in FIG. 5B;

FIG. 6B is a schematic diagram illustrating shifting of two ferro-fluid/magneto-rheological fluid components shown in FIG. 5A;

FIG. 7 is an elevation view illustrating another magnetic field generating component on the top lid shown in FIG. 5B;

FIG. 8 is a cross-sectional view illustrating a pump module after the second embodiment shown in FIG. 5A is assembled;

FIG. 9A is a cross-sectional view illustrating operation of the opening control device in its suppky mode according to the embodiment shown in FIG. 8;

FIG. 9B is a cross-sectional view illustrating operation of the opening control device in its pump mode according to the embodiment shown in FIG. 8;

FIG. 10 is a schematic diagram illustrating operations of the embodiment shown in both FIGs. 9A and 9B when the fluid switching function is installed;

FIG. 11 is a cross-sectional view illustrating thin-film type micro pump;

FIGs. 12A and 12B are cross-sectional views illustrating a conventional piezoelectric type micro pump; and

FIG. 13 is a schematic diagram illustrating operation of a conventional ferro-fluid/magneto-rheological fluid driven micro pump.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

According to the present invention, a micro pump using ferro-fluid/magneto-rheological fluid is fabricated in the microelectromechanical (MEM) process and comprises a plurality of micro pump components assembled together. FIG. 1 is a

cross-sectional view of a micro pump according to the first embodiment of the present invention. Referring to FIG. 1, a silicon substrate body comprising a first body 10 and a second body 15 is provided such that an accommodating space 20 within the silicon substrate body is formed from recess portions of the first and second bodies 10 and 15. Two openings are formed at the junction gaps between the two bodies 10 and 15 to serve as an entrance 21 and an exit 22 for a working fluid on two corresponding sides of the accommodating space 20. A polydimethylisiloxane (PDMS) membrane 30 is formed in the accommodating space and located above the entrance 21 and the exit 22 to separate the accommodating space 20 into a first space 25 and a second space 26. As a result, the entrance 21 and the exit 22 communicates the second space 26 to outside, and the second space 26 serves as a channel through which the working fluid flows in/out of the micro pump 1.

The first space 25 is filled with a ferro-fluid/magneto-rheological fluid 40. The ferro-fluid/magneto-rheological fluid 40 may be nano particles/micro particles consisting of iron or oxidized iron, so as to transform instantly the fluid from a liquid form to a solid form when the magnetic particles in the fluid are magnetized by the magnetic field. Also, a magnetic field generating unit, such as an electromagnet switch 50 is disposed in the second body. The electromagnet switch 50 applies a forward and reverse magnetic field to the accommodating space 20 constantly using a positive/negative voltage based on a predetermined frequency.

The PDMS membrane 30 described above may be selected from other silicone materials. For example, the membrane may include a polymethylphenylsiloxane (PMPS) membrane, a polydiphenylsiloxane (PDPS) membrane or other co-polymers, such as poly(dimethylisiloxane)-co-poly(diphenylsiloxane). Other polymer materials,

including polypropylene (PP) and polyethylene (PE) may also be used to fabricate the membrane 30 having a thickness of about 25 μm with excellent retractility. The present embodiment is not limited to generating the forward/reverse magnetic field using the electromagnet switch 50, other magnetic field generating units that generate the magnetic field and drive the ferro-fluid/magneto-rheological fluid 40 based on the pre-determined frequency may similarly be disposed in the second body 15. The entrance 21 and exit 22 formed at junction gaps between the first and second bodies 10 and 15 may be designed according to the MEMS process as a diffuser 23 and a nozzle 24, respectively, to replace valves of the conventional micro pump. An opening control device (not shown) may be further formed on the diffuser 23 and the nozzle 24 to match operations of the electromagnet switch 50 in opening or closing the entrance 21 or exit 22 at appropriate time. As a result, the highest fluid transmission efficiency is achieved and back flow of the working fluid is prevented. The design and operation of the micro pump are described in detail below.

The micro pump described in the first embodiment uses the ferro-fluid/magneto-rheological fluid 40 in the first space 25 as a driving source to drive the working fluid to input in the second space 26 or output from the second space 26. The operation process begins by switching on the electromagnet switch 50 to apply forward/reverse magnetic field to the accommodating space 20 of the body constantly. The ferro-fluid/magneto-rheological fluid 40 in the first space 25 is magnetized constantly by magnetic fields from different directions. This causes particles in the ferro-fluid/magneto-rheological fluid 40 to align in the same magnetized direction under attraction of the magnetic fields, resulting instant solidification of the ferro-fluid/magneto-rheological fluid 40 as shown in FIG. 2B. During de-magnetization, the

particles are bombarded by the ferro-fluid/magneto-rheological fluid molecules to move in brownian motion, so as to evenly distribute in the form of liquid as shown in FIG. 2A. As the ferro-fluid/magneto-rheological fluid 40 is magnetized to form the solid, the magnetic solid 40 is attracted by magnetism of the electromagnet switch 50 to compress the PDMS membrane 30, causing deformation of the PDMS membrane 30. This further leads to compression for the second space 26 as shown in FIG. 3A, so that output of the working fluid from the second space 26 is greater than input of the working fluid to the second space 26. The micro pump then performs a pump mode operation. On the other hand, when the electromagnet switch 50 is subjected to a lower voltage by a voltage function designed as sine wave to apply a smaller magnetic field to the accommodating space 20, the attraction applied to the magnetic solid 40 is smaller than a restoring force of the PDMS membrane 30, so that the PDMS membrane 30 is deformed and restored to its original position in opposite direction to compress the first space 25, while the second space 26 that is filled with the working fluid is enlarged as shown in FIG. 3B. Meanwhile, input of the working fluid to the second space 26 is greater than output of the working fluid from the second space 26. The micro pump then performs the supply mode operation to complete an entire pump cycle and achieve efficiency in driving the working fluid.

In the micro pump of the present embodiment, the electromagnet switch 50 has a switching frequency of 1000 Hz and above, while the phase change for the ferro-fluid/magneto-rheological fluid 40 is completed within microseconds. Therefore, the PDMS membrane 30 may be able to vibrate reciprocally at the frequency of 1000 Hz, and the working fluid may be driven accordingly to achieve a driving frequency of 1000 Hz and above.

Since the PDMS membrane 30 is highly retractable, the electromagnet switch 50, besides plays a role in applying the forward/reverse magnetic field, may alternate between actions of applying magnetic field and removing magnetic field to achieve the same reciprocating vibration of the PDMS membrane 30. At the instant when the magnetic field is removed, the magnetic solid 40 is changed into the ferro-fluid/magneto-rheological fluid. The fluid is no longer attracted by the electromagnet switch 50, so the PDMS membrane 30 is quickly deformed to retract, achieving the same pump cycle as shown in both FIGs. 3A and 3B.

Summarizing from the above, it is understood that the driving source in the first embodiment is the ferro-fluid/magneto-rheological fluid 40 that is controlled by additional magnetic fields. And frequencies for the magnetic field variation and phase change of the ferro-fluid/magneto-rheological fluid are quite high. Therefore, the PDMS membrane 30 may have a significantly high deformation level and deformation frequency to drive a higher flow than the micro pump in the prior art does and to precisely regulate the flow via the magnetic field. Accordingly, the present embodiment may be implemented in the micro cooling/air conditioning system that requires a large flow or a biomedical system that requires a precise flow. In the present embodiment, moving parts and valves associated with the conventional design may be omitted to avoid wearing of the extra components or loss of fluid pressure. With the opening control device, the closure of the entrance and exit is controlled to prevent contamination due to back flow of the working fluid. And the entire micro pump structure is not limited by its appearance as it has the ferro-fluid/magneto-rheological fluid in liquid form.

The present embodiment is described with a single micro pump component 1 as an example. However, a plurality of micro pump components 1 may also be assembled as shown in FIG. 4 in the micro pump using the ferro-fluid/magneto-rheological fluid to increase the entire flow to be driven as well as to extend applicable fields of the present invention.

FIG. 5A is an elevation view illustrating the micro pump without a top lid disposed thereon according to the second embodiment of the present invention. The second embodiment is described with a single micro pump component 2 as an example. FIG. 5B illustrates a top lid 55 of the micro pump 2 according to the second embodiment of the present invention. Referring to FIG. 5A, the micro pump comprises a silicon substrate body 60 having an accommodating space 65, and an entrance 61 and an exit 62 are formed respectively on both sides of the body. The entrance 61 and the exit 62 are designed as a diffuser 63 and a nozzle 64 respectively to open to the accommodating space 65 and serve as openings for the working fluid to flow in and out of the accommodating space 65. So, the accommodating space 65 becomes a channel for the working fluid. Each of the two corresponding sides of the accommodating space 65 is filled with a ferro-fluid/magneto-rheological fluid unit 70 so that both the ferro-fluid/magneto-rheological fluid unit 70 and the working fluid are located in the accommodating space 65.

The ferro-fluid/magneto-rheological fluid unit 70 is a ferro-fluid/magneto-rheological fluid immiscible to the working fluid or a ferro-fluid/magneto-rheological fluid that is molded by encapsulating in the PDMS membrane. Since contamination of the working fluid reduces the operating efficiency of the pump. If it is possible for the ferro-fluid/magneto-rheological fluid to be miscible to the working fluid, the ferro-

fluid/magneto-rheological fluid needs to be encapsulated and isolated by the PMDS membrane to prevent the ferro-fluid/magneto-rheological fluid from contaminating the working fluid. Similarly, the ferro-fluid/magneto-rheological fluid has nano particles such as iron or iron oxide described in the first embodiment. And the PDMS membrane may also be substituted with other materials that produce the equivalent effect.

The top lid 55 shown in FIG. 5B is disposed on the body 60 illustrated in FIG. 5A in such a way that the top lid 55 seals up the accommodating space 65. Two movable magnets 56 are disposed on the top lid 55 to correspond to position of the ferro-fluid/magneto-rheological fluid unit 70 in the accommodating space 65, so that the ferro-fluid/magneto-rheological fluid unit 70 is magnetized by the movable magnets 56 to form a magnetic solid. And the magnetic solid is driven to shift position when the movable magnets 56 move.

Therefore, the movable magnets 56 on the top lid 55 serve as a driving source for the micro pump of the second embodiment. As shown in FIGs. 6A and 6B, the two movable magnets 56 move to the center of the top lid 55 to drive two corresponding ferro-fluid/magneto-rheological fluid units 70 to shift until they approach to each other. The working fluid in the accommodating space is then squeezed by the two ferro-fluid/magneto-rheological fluid units 70, so that output of the working fluid via the exit 62 is greater than input of the working fluid via the entrance 61, and the micro pump performs a pump mode operation. On the other hand, when the movable magnets 56 are driven to repel from each other until they return to two corresponding sides of the top lid 55, the input of the working fluid via the entrance 61 is greater than the output of

the working fluid via the exit 62 due to a pressure drop in the accommodating space 65. And the micro pump performs a supply mode operation to complete one pump cycle.

Thus, if the frequency of reciprocating movement for the movable magnets 26 is adjusted to 1000 Hz and above, the frequency of reciprocal shifting for the ferro-fluid/magneto-rheological fluid units 70 may also reach 1000 Hz to drive the working fluid, achieving a driving frequency of 1000 Hz and above.

The top lid 55 in this embodiment is not limited to the design shown in FIG. 5B, the entire surface of the top lid 55 may also be disposed serially with rows of electromagnets 57 as illustrated in FIG. 7. The magnetic field of the electromagnets 57 may be initiated in sequence from two sides of the top lid 55 to its center as indicated by arrows in the diagram, so as to achieve the equivalent magnetic field shifting effect produced by the movable magnets 56 in FIG. 5B. As a result, the two corresponding ferro-fluid/magneto-rheological fluid units 70 shift in the accommodating space 65 until they approach each other, in order to produce a satisfactory fluid driving effect.

The micro pump components 2 in the second embodiment can be assembled to each other as shown in FIG. 8 (the top lid is not shown). A greater flow of the working fluid is then output, making it feasible to implement the micro pump of this embodiment in the micro cooling/air conditioning system that requires a large flow. And an opening control device may be disposed on the diffuser 63 and nozzle 64 as well as the entrance 61 and exit 62 shown in both FIGs. 9A and 9B. The opening control device in this case is the same as the opening control device described in the first embodiment and includes a plurality of ferro-fluid/magneto-rheological fluids 71a and 71b driven by the magnetic field to shift via magnetic field variation within a first channel 72 on an entrance side and a second channel 73 on an exit side. As the

opening control device and the ferro-fluid/magneto-rheological fluid units 70 in the accommodating space 65 are integrated to shift synchronously by the magnetic field, satisfactory effects in terms of ideal flow and flow direction control are achieved. For example, when the micro pump is operated at the supply mode as shown in FIG. 9A, the ferro-fluid/magneto-rheological fluid units 70 are arranged on two sides. The ferro-fluid/magneto-rheological fluid unit 71b in the second channel on the exit side then shifts to seal up the exit 62 of the accommodating space, so that the working fluid can flow from the entrance 61 on the entrance side into the accommodating space 65. On the other hand, when the micro pump is operated at the pump mode as shown in FIG. 9B, the ferro-fluid/magneto-rheological fluid units 70 are driven by the magnetic field on the top lid 55 to shift until they approach each other. As a result, the working fluid in the accommodating space 65 is squeezed while the ferro-fluid/magneto-rheological fluid unit 71a in the first channel 72 on the entrance side shifts to seal up the entrance 61 of the accommodating space 65. The working fluid in the accommodating space 65 then flows out only from the exit 62 on the exit side. Thus, the flow direction is precisely controlled without causing back flow of the working fluid as well as contamination for the working fluid associated with use of the conventional micro pump.

Referring to FIG. 10, an embodiment of the micro pump is illustrated with a fluid switching function is further installed on the opening control device according to FIGs. 9A and 9B, so as to more precisely control input or output of the working fluid. In the operation mode shown in the diagram, the working fluid is discharged out via shifting of the ferro-fluid/magneto-rheological fluid unit 70. Then, with the fluid switching function, the magnetic field control is operated to cause shifting of the ferro-

fluid/magneto-rheological fluid unit71b in the second channel 73. Consequently, the exit 62 is open to allow the desired working fluid to output from the exit 62 of the micro pump, so as to fulfill requirements for both a large flow and precise flow control. Therefore, the present invention is feasible to implement in the biomedical system that requires precise flow control.

Summarizing from the second embodiment above, a greater flow is driven using the external magnetic field and position shift of the ferro-fluid/magneto-rheological fluid unit 70, regardless of whether the micro pump is made of a single micro pump component 2 or a plurality of micro pump components 2. Furthermore, the flow can be precisely controlled via the magnetic field, while the moving parts and valves associated with the conventional micro pump structure may be omitted to prevent wearing out of extra components or loss of fluid pressure. And with the opening control device, closure of the entrance 61 and exit 62 may be controlled to prevent back flow of the working fluid that causes contamination. The entire micro pump structure is also not limited by its appearance since the ferro-fluid/magneto-rheological fluid in the accommodating space 65 is in liquid form.

According to the present invention, a micro pump using the ferro-fluid/magneto-rheological fluid is proposed. The micro pump controls deformation and position shifting of the ferro-fluid/magneto-rheological fluid precisely and quickly using the additional magnetic field to drive the working fluid, so that drawbacks associated with using the conventional micro pump are resolved.

It should be apparent to those skilled in the art that the above description is only illustrative of specific embodiments and examples of the invention. The invention should therefore cover various modifications and variations made to the herein-

described structure and operations of the invention, provided they fall within the scope of the invention as defined in the following appended claims.